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POWERING CAMPUS STREET LIGHTS USING HUMAN MOVEMENT

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ABSTRACT

The rate of growth of the human population is increasing, resulting in demand for stable, affordable, sustainable, and eco-friendly electricity, especially in developing countries. This study used the growing population problem to solve the problem of electricity. The study developed electricity to power streetlights on campus by converting the daily human movements on campus using a piezoelectric sensor/tile. A piezoelectric tile prototype was built and tested for efficiency. Pressure was exerted on the piezoelectric tile by human movement, which was converted to an electrical charge. The piezoelectricity generated was connected to a bridge rectifier to make it stable and convert the AC to which charged a capacitor. Eight piezoelectric discs were arrayed in series. A piece of cardboard was placed on the spring and piezo circuit to obtain the optimum output. Also, a plastic sheet of 8mm thickness and 1 square foot surface area for pressure and weight distribution was used. The total voltage in series obtained was 26.38 V for the piezo disc arrays, 38 V for the weight on the piezoelectric tile, and 40 W was recorded as the maximum wattage. Although the existing campus streetlight is powered by 54.1 V (20 W for some solar streetlights) with a wattage of about 18 W to 150 W, the power obtained was deployed on low energy consuming bulbs.

KEYWORDS: Piezoelectric, Human Movement, Electricity & Campus Streetlights

Original Article

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INTRODUCTION

The shift towards the fourth industrial revolution and cleaner energy has led to a series of research studies geared towards sustainable and affordable energy access. Studies on converting human movement into energy seem to suggest that it is low maintenance, affordable, sustainable, and eco-benign (Hossain and Uddin, 2021;Maharjan et al., 2019; Pillatsch et al., 2016; Shao, 2021). University campuses are breeding grounds for innovators, leaders, and policymakers who will shape human existence. However, insecurity and electricity can negatively affect a conducive learning environment on such campuses. University campuses face the same problems of stable, affordable, and sustainable energy supply occasioned by the growing human population (Semieniuk et al., 2021; Ukoba et al., 2018). It is estimated that both public and private institutions investan estimated 20 % to 40% of total electricity supplies on streetlighting (Subramani et al., 2019). This article aims to reduce the cost associated with grid electricity streetlights and provide a green energy solution to streetlighting using human movement as the power source. The study used a university with an estimated 50000 students as a case study.

Streetlightsare a publicly accessible system with low voltage loads that illuminate areas at night for safety and ease of access (Parise et al., 2011;Chalfin et al., 2020). Cities in developing countries tend to be without streetlights, thereby encouraging crime and other vices associated with darkness. The growing population has resulted in research on converting human movement into energy.

Piezoelectric sensors are used to generate electricity when a piezo disc is compressed or strained. A piezoelectric disc is a device that converts pressure into alternating current (AC). Thereafter, a rectifier is used to convert the generated AC into direct current (DC). The DC is stored by a capacitor and/or rechargeable batteries for powering devices. A single person can generate 3 Wto 18 W depending on their pressure on the piezoelectric device (Laskar, 2017). Similarly, a 60kg human can generate 0.1 watt-seconds for every second (Majeed, 2015). Human movement was used to generate 10000 watt-seconds per day using piezoelectric tiles of 6 m^2, equivalent toa100 W bulbs for 1.666 minutes, in 2006 by the Japan Railway Company (Scholer et al., 2009). Human movement has been used to power a section of Abu Dhabi Airport and a nightclub in the Netherlands. This study used human movement to generate electricity for a campus streetlight using a piezoelectric tile.

2. PRINCIPLE OF ENERGY GENERATION OF PIEZOELECTRIC

Piezoelectricity is generated when a strain/pressure is applied to a crystalline material resulting in opposite charges on both sides of the material with electricity generated as a result. This is caused by the asymmetric polarity present in the piezoelectric material. The pressure applied to the piezoelectric material is directly proportional to the electricity generated (Umeda, Nakamura and Ueha, 1996). Piezoelectricity is dependent on the crystallineproperty of the material,the thickness, andthe force applied on the piezoelectric tile (Nia, Zawawi and Singh, 2017).

Energy generated by piezoelectricity is minimal compared to other harvesting methods hence an efficient temporary energy storage (rechargeable batteries or capacitors) is required (Umeda, Nakamura and Ueha, 1997).Electricity has been generated using piezoelectric human movement by embedding piezoelectric devices on floors, roads, railways, stadiums and airports (Evans, 2015).

3. METHODOLOGY

3.1 Experimental Design

The experiment was designed using equation 1

$$P = f\ (\text{weight, battery, wire, spring}) \quad (1)$$

Where:

P is a dependent variable (Power) and f is independent variables (weight, battery, spring, wire).

Figure 1 shows a schematic representation of the human movement using piezoelectric material.

Figire 1: Schematic Representation of Human Movement on Campus (Panchakshari et al., 2016).

The experimental design schematic is shown in figure 2. Human footsteps applied a strain on the acrylic plastic collection plate and piezoelectric material. The output AC was connected to a rectifier that produced DC. The DC generated was stored by a storage device (rechargeable batteries).

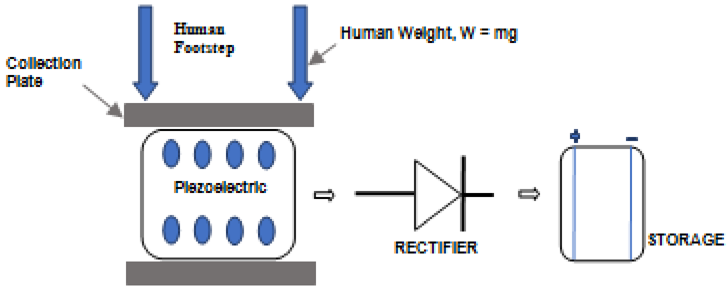

Figure 2: Schematic of the Experimental Setup.

Figure 3 shows the circuit design and connection of the piezo disc array. The piezoelectric material was connected with wires using a soldering iron after testing the functionality of each disc.

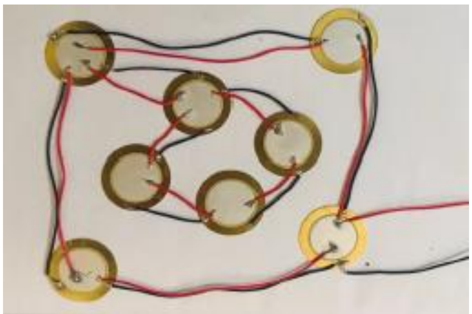

Figure 3: Piezoelectric Circuit Connection of the 8 Piezo Disc Array.

Figure 4 was achieved by mounting the piezoelectric circuit on the collection plate and base plate using cardboard and connecting a multimeter to take readings. The diameter of the piezoelectric material was 15mm, the thickness was 8mm, and the tile occupied an area of 1square foot.

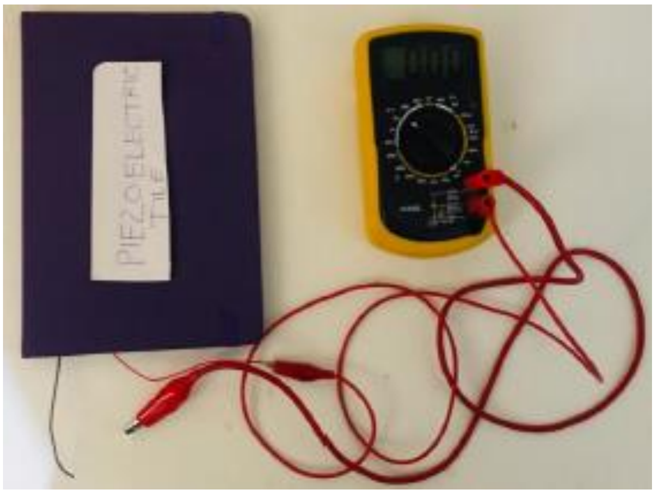

Figure 4: The Complete Piezoelectric Circuit without Loading (without Human Foot Interaction).

4. RESULT AND DISCUSSIONS

From equation 1, there are several independent variables and one dependent variable of power. This study considered two independent variables, namely, piezo disc array and weight. For variable 1, the piezo disc array was considered as follow.

Variable 1

$$P = f(\text{piezo disc array}) \quad (2)$$

A multimeter was used to obtain readings for the various disc arrays, as given in equation 2. The initial multimeter reading of a piezo disc gave 2.52 volts and 0.005mA. The power was found to be 12.60mWusing Watt’s law. A total of eight piezo discswere used for the experiment, and the readings are tabulated in Table 1.

Table 1: Voltage and Current Generated from the Different Numbers of Piezoelectric Disc

Number of Piezo Discs	Voltage (V)	Current (mA)
1	2.52	0.005
2	3.35	0.007
4	4.51	0.0068
6	6.50	0.008
8	9.50	0.0081

Figure 5 shows the graph of the piezo disc array against the voltage. The plot shows the output voltage was almost proportional to the number of piezo discs,although it is evident that there was a larger increase in voltage as the number of disc arrays increased from four pieces.This observation is due to the series arrangement of the piezo disc array.

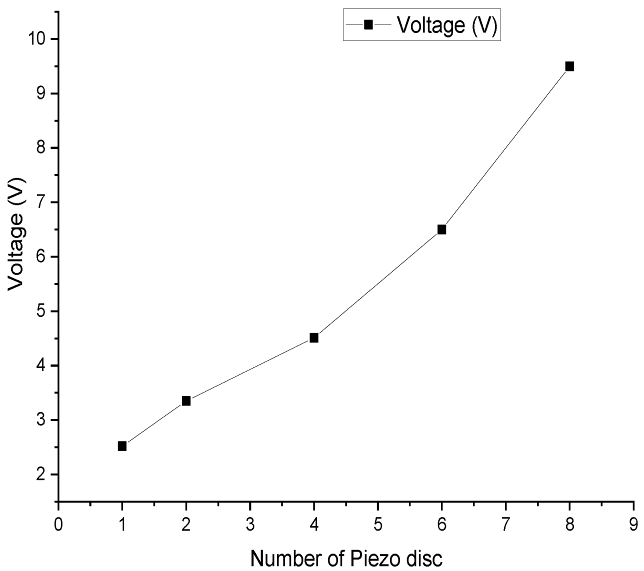

Figure 5: Graph of Eightpiezoelectrics Discs against Output Voltage.

Figure 6 shows a plot of current generated from the eight piezo disc array. The plot gave a repeated pattern of sharp increases and steep current when the number of piezo discs in the array was increased.

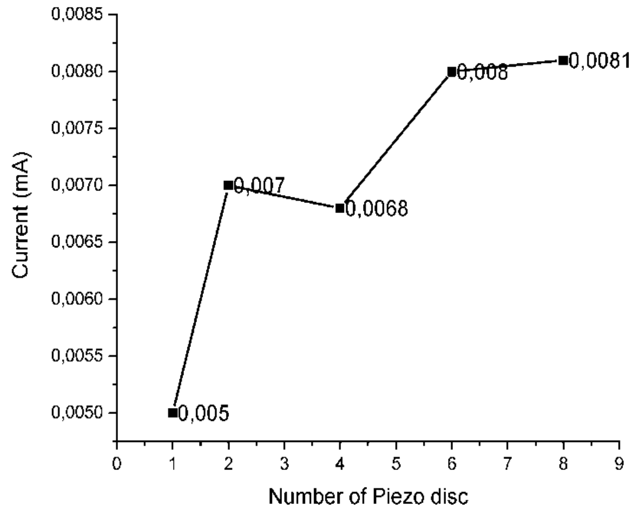

Figure 6: A Plot of the Current output of Different Number s of Piezo Discs in the Array.

Figure 7 shows the plot of the power generated from the eight piezo disc array with a diameter of 15 mm,thickness of 8 mm occupying an area of 1 square foot and connected in series. This is generated from Table 2. From the graph, it was observed that the power generated was directly proportional to the piezoelectric disc array. This result of optimum power obtained from increment in the size of the piezoelectric disc array agrees with Kim et al. (2019) in which an electromagnetic energy harvester produced optimum power from increases in the disc array.

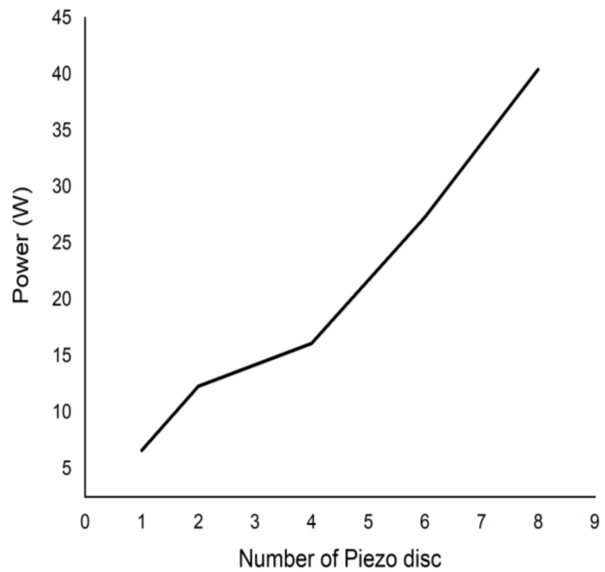

Figure 7: A plot of Power Generated from Square Foot Piezoelectric.

Table 2: The Power Generated from the Different Numbers of Piezoelectric Discs

Number of Piezo Disc	Power (W)
1	6.62
2	12.32
4	16.12
6	27.33
8	40.44

Variable 2: Weight of human movement was used for the second variable and discussed as follows. From the literature (Lee and Nieman, 2013; Mchiza et al., 2015) and random sampling measurement performed on campus users, it was discovered that the weight of campus users is between 45 kg to 110 kg. These values were used as an input parameter in equation 3.

$$P = f(Weight) \tag{3}$$

$$W = mg \tag{4}$$

Where:

W is the weight or force, m is mass and g is acceleration due to gravity.

But,

$$\text{Pressure, p} = \frac{W}{A} \tag{5}$$

Where:

A is area and W is weight.

A commercial 2W10 bridge rectifier was used to convert the AC generated from the piezoelectric into DC. A 2W10 bridge rectifier single-phase rectifier hasa silver-plated copper lead and plastic case. The rating and characteristics are shown in figure 8.

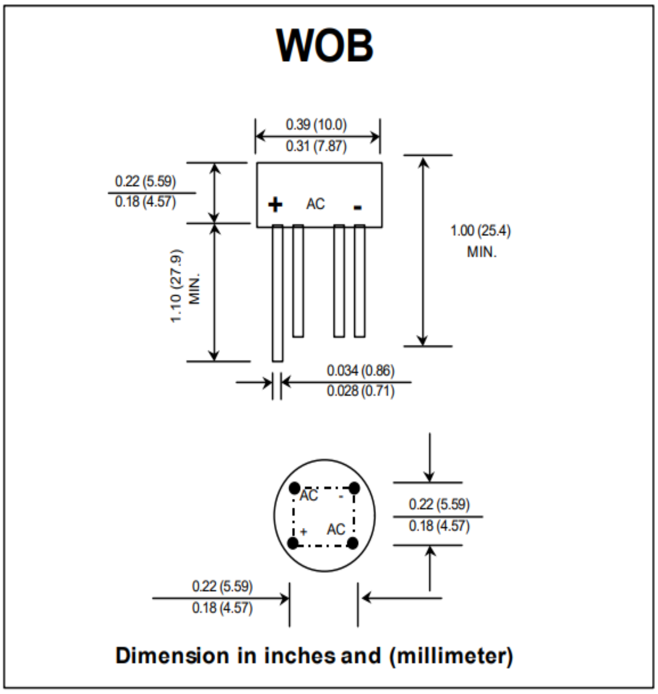

Figure 8a: Dimensions.

RATING	SYMBOL	2W10	UNIT
Maximum Recurrent Peak Reverse Voltage	V_{RRM}	1000	Volts
Maximum RMS Voltage	V_{RMS}	700	Volts
Maximum DC Blocking Voltage	V_{DC}	1000	Volts
Maximum Average Forward Current 0.375" (9.5 mm) lead length Tc = 25°C	$I_{F(AV)}$	2.0	Amps.
Peak Forward Surge Current Single half sine wave Superimposed on rated load (JEDEC Method)	I_{FSM}	50	Amps.
Rating for fusing (t < 8.3 ms.)	I^2t	10	A^2S
Maximum Forward Voltage per Diode at I_F = 1.0 Amp.	V_F	1.0	Volts
Maximum DC Reverse Current Ta = 25 °C	I_R	10	μA
at Rated DC Blocking Voltage Ta = 100 °C	$I_{R(H)}$	1.0	mA
Typical Junction Capacitance per Diode (Note 1)	C_J	24	pf
Typical Thermal Resistance (Note 2)	RθJA	36	°C/W
Operating Junction Temperature Range	T_J	- 50 to + 150	°C
Storage Temperature Range	T_{STG}	- 50 to + 150	°C

Figure 8b: Maximum Ratings and Electrical Characteristics of the 2W10 Bridge Rectifier (EIC Discrete Semiconductor, 1998).

The rectified voltage was plotted against the weight of campus users, as shown in Figure 9. It was observed that the maximum voltage was recorded for a weight of 80 Kg. The existing streetlights specification is shown in Table 3. The total voltage of 38 V is within the range of the specified voltage for the existing campus streetlight. Also, the 40 W obtained is within the wattage specification of the existing lamps on campus and commercial solar streetlight ratings (Yogesh et al., 2020).

Table 3: Specification of Campus Streetlight

Factor	Lamp
Wattage	18 to 150
Efficiency (lumen/watt)	72 to 115
Output (lumen)	3,600 to 46,000
Lumen maintenance (%)	90(70)
Lamp life (hours)	18000 to 24000
Energy use	Low
Colour rendition	Moderate
Voltage (V)	54.06

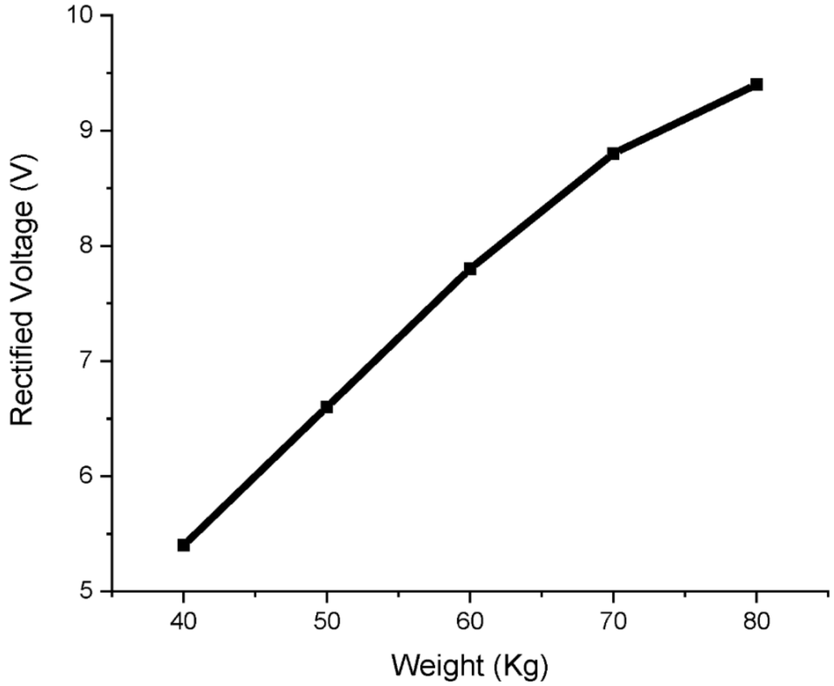

Figure 8: A Plot of Rectified Voltage for the Various Weight of Campus users on Piezoelectric.

CONCLUSIONS

The shift towards the fourth industrial revolution and cleaner energy has led to a series of research studies and converting human movement into energy has been demonstrated in this study. This study developed a device capable of powering streetlights on campus and other related areas. The device can generate 38 volts and 40 watts from an eight piezo disc array and the weight of several humans. A linear relationship was found to exist between human weight and the energy generated. Also, the number of piezo disc arrays was directly proportional to the piezo disc arrays. This study shows that a piezoelectric installation is self-sustaining, environmentally friendly, cheap, easy to maintain, and can be installed in areas with human traffic, including stadiums and railway stations.

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